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USE OF THE RENDEZVOUS RADAR FOR GUIDANCE MONITORING AND FAILED GUIDANCE SYSTEM DETECTION DURING THE LM POWERED DESCENT

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SUMMARY

An analysis of the rendezvous radar as a guidance monitoring and failure detection and isolation device during powered descent is made. The results indicate the tracking radar is of little value to the crew in this respect, largely because of the tape indicator limitations and the large descent engine thrust uncertainties.

INTRODUCTION

The role of the rendezvous radar (RR) in guidance monitoring and as a failed guidance system detection and isolation device during the powered phases of the LM mission has been the subject of discussion for some time. An analysis of the descent guidance monitoring requirements (reference 1) examined the use of the RR during the LM powered descent. The analysis failed to identify the RR as a requirement in powered descent, but concluded that the crew could use it if they desired. To assure, however, that time would be available for use of the RR, reference 2 recommended to the AS-504 Flight Operations Plan panel that time be allocated in the mission time-line for crew monitoring of the powered phases using the RR. Because of the reference 2 recommendation, it appears timely to enumerate some of the problems associated with use of the RR in powered descent and to explain what can be expected of it during this phase.

RENDEZVOUS RADAR AND TAPE METER

The RR, according to specifications, is expected to give CSM-LM relative range and range rate to the 1/4% in the ranges encountered during powered flight, but angular information will probably be of doubtful quality (reference 2). Range data will have a bias of the order of 500 feet and range rate data a bias of 1 ft/sec. Because the RR primary guidance computer interface is to be locked out during descent, all RR data must be read from the tape displays. With this display, resolution of crew-read range will be 1 n.m. over the 0-400 n.m. tape range and the range rate resolution 0.5 ft/sec over the $\pm$700 ft/sec range. As noted, there will be no LOS or $\dot{\text{LOS}}$ data available in powered flight.

CSM-LM Relative Range-Range Rate Schedule During Powered Descent

A review of the nominal AS-504 reference trajectory shows that the range-range rate schedule listed in Table I occurs during the first 400 seconds of powered descent. From Table 1, it is apparent that relative range rate

Time (sec)	CSM-LM Relative Range (n.m.)	CSM-LM Relative Range Rate (ft/sec)
0	178	+670
100	183	-135
150		-670 (display limit)
200	174	-1150
300	146	-2100
400	106	-2600

Table 1 - AS-504 Powered Descent Range-Range Rate Schedule

is not available to the crew past 150 seconds into the descent but that relative range can be used throughout the time period indicated.

Use of Range-Range Rate Tape Indicator

As far as the crew is concerned, the tape display can be read to 1 n.m., but because of range and meter inaccuracies, the relative range uncertainty as read from the display is of the order of 2 n.m. throughout the descent. The static resolution of the range rate tape indicator is 0.5 ft/sec, but the tape indicator RR-range rate errors cause the estimated resolutions to be of the order of 2 ft/sec at the start of burn, 1 ft/sec at 100 seconds, and 3 ft/sec at 200 seconds. This, however, is an optimistic estimation because range rate is changed at a rate of the order of 10 ft/sec/sec and greater in descent. Whether the crew can read the tape meter to these accuracies under dynamic conditions is questionable. But this is of academic interest, as will be shown later.

RANGE AND RANGE RATE DISPERSIONS

The CSM-LM relative range and range rate measured by the RR have dispersions which arise from a combination of navigational, primary guidance system, and descent engine thrust uncertainties. The dispersions of primary significance are those caused by the descent engine thrust uncertainty, which can be as large as ±4% about the nominal thrust. Because of this large thrust uncertainty, the deviation from the reference trajectory range and range rate schedule following the start of burn is also large. Thus, attempting to relate range and range rate to time to obtain useful information is difficult. To illustrate this, the disper-

	3σ Range Dispersion (n.m.)		3σ Range Rate Dispersion (ft/sec)	
Time	G&N	Engine	G&N	Engine
0	0.50	0	3.0	0
100	0.52	.37	6.0	42
200	0.55	1.47		
300	0.58	3.0		
400	0.66	5.1		

Table 2 - 3σ Range and Range Rate Dispersion

sions in range and range rate arising from the G&N uncertainties and those caused by the ±4% engine thrust uncertainty have been listed in Table 2. The large range and range rate uncertainties, coupled with the lack of precise tape readout data, give rise to the problems of using the RR in guidance monitoring and failure detection.

DISCUSSION OF RESULTS

The analysis of reference 1 contains discussion of both guidance monitoring and failed system isolation. Also contained in that reference is a technique for determining the level of trajectory deviation necessary before the crew is assured of a 99.86% chance of detecting a failure. The results of that analysis have been used to specifically analyze the rendezvous radar with respect to guidance monitoring and failure detection.

Guidance Monitoring

The RR as a monitoring device must be used in an indirect manner. As neither guidance system computes relative range rate, the crew must rely on a graph of time history of both range and range rate and compare this to the actual RR measurement at the time of suspected failure. If the RR measures within the expected limits, the abort system is assumed failed and if otherwise, the primary system is assumed failed.

Use of Range Rate - In monitoring range rate, it is apparent from Table 1 and the limitations of the tape indicator that the crew cannot use range rate for more than 150 seconds of the descent. Furthermore, the crew, in reading the tape, cannot be certain of range rate to better than 2 ft/sec, which is within the initial guidance dispersion of 3 ft/sec. Thus, if they can interpolate the tape reading to 3 ft/sec at the start of descent, they are at least assured that the trajectory is within the 3σ bounds. However, at 100 seconds, the engine-guidance dispersions are of the order of 42 ft/sec and range rate data are of questionable value in monitoring because the engine thrust uncertainty has masked all other uncertainties. About the only useful information derived from checking range rate would be whether the engine was or was not operating within its expected 3σ thrust uncertainty.

Use of Range - The use of relative range to obtain a check on guidance performance also leads to the same conclusion. Note that the expected 3σ guidance dispersion at the start of descent burn is about 0.5 n.m. and that the tape indicator can be read to no better than 2 n.m. In this case, the measuring instrument is four times worse than the guidance system which means that the crew at best would be able to detect a failure causing a 12σ range deviation. The ability to detect smaller trajectory deviations becomes better as the descent continues, but only because the engine dispersions swamp the guidance errors. As in the case of range rate, the only thing relative range will tell the crew is that the engine is operating or not operating within its expected thrust range.

Effect of Reducing Thrust Uncertainties to 2% - As an additional item it should be noted that changing the engine thrust uncertainty to ±2% does not necessarily alter the situation. The range rate uncertainty at 100 seconds changes to about 22 ft/sec of which 6 ft/sec arises from the guidance system and 21 ft/sec can be attributed to the engine. The range problem still exists too because the tape indicator cannot be read to the required accuracy and also because of the large range dispersion.

Failed System Detection

Detection of a failed guidance system has been shown to be difficult because of the engine thrust uncertainties coupled with the tape display resolution problems. It is of interest, however, to calculate the trajectory deviations that can be detected and then relate these deviations to guidance component failures.

Trajectory Deviations Required for 99.86% Detection Level - The engine-guidance dispersions have already been shown in Table 1. To assure a 99.86% level of failure detection, the trajectory range uncertainty and RR-tape indicator uncertainty must be added together and then rounded off to an integral number as the tape meter range resolution is no better than 1 n.m. Likewise, the RR and tape meter range rate uncertainties must be added to the trajectory uncertainty and rounded off to the nearest 0.5 ft/sec. To a first approximation, multiplying these numbers by 3 gives the number of 1σ trajectory deviations that must occur before there is at least 99.86% chance of detecting that a failure has occurred. The results of these calculations are shown in Table 3. Notice that the trajectory deviations for detection become smaller as the descent time increases. This would be expected as the engine uncertainties predominate and the range uncertainty eventually causes the tape indicator reading to become more accurate relative to the range dispersion.

	Range		Range Rate	
Time (sec)	Range Error for 99.86% Detection	Trajectory Error (σ)*	Range Rate Error for 99.86% Detection	Trajectory Error (σ)
0	2.50 (3.0)n.m.	18	5.0 ft/sec	5
100	2.64 (3.0)	14.1	42.6 (43)	3.1
200	3.56 (4.0)	7.7	78.7 (79)	3.1
300	5.0 (5.0)	5.0		
400	7.1 (8.0)	4.1		

*(1σ = 1 standard deviation)

Table 3 - Trajectory Deviations Required for 99.86% Detection Level

<u>Magnitude of Component Failures for 99.86% Detection Level</u> - Assuming that the failed guidance system would be isolated at the instant a failure is detected, the data of Table 3 can be related to guidance component failure magnitude. These magnitudes have been listed in Table 4 for selected components.

	Accelerometer Bias (σ)		Misalinement (σ)		Gyro Drift (σ)	
	Range	Range Rate	Range	Range Rate	Range	Range Rate
Time						
0						
100	2020	284	233	40	2270	434
200	705		87		685	
300	485		68		470	
400	370		53		357	

Table 4 - Magnitude of Guidance Component Failures Detectable by Using RR Measurement of Range and Range Rate

The level of component failure that must occur before a guidance failure can be detected is large and results almost entirely from the effect of the engine thrust uncertainty in the powered descent coupled with the display resolution and inaccuracies of the RR. Such failure levels constitute a complete disruption of the primary guidance system functions, and it is very likely the crew would be aware of these failures long before the RR could detect them. As a note of interest, reference 1 shows that the same component failures can be detected at a level one tenth of those listed in Table 4 by monitoring altitude, altitude rate, and lateral velocity using the landing radar or MSFN.

CONCLUDING REMARKS

The RR, based on this analysis, appears to be of questionable value in either monitoring guidance system performance or in detecting and isolating a failed guidance system by casting the majority vote. The reasons for this are: (1) the inability of the crew to read and interpret the range-range rate tape meter coupled with the expected RR error and (2) the effect of the $\pm 4\%$ thrust uncertainty of the descent engine on the trajectory which effectively swamps the guidance system errors. This situation results from the fixed throttle limitation which restricts the guidance system range adjustments until after approximately 400 seconds. In the range-free guidance scheme, of course, no attempt is made to adjust for the deviations in range. An improvement in monitoring would be possible by having either the primary or abort guidance computers calculate relative range and range rate during descent. This arrangement would allow the RR measurement of range and range rate to be compared directly with the computer estimation of the same quantities. If, however, the solution of range and range rate by either guidance system is not possible, then an improvement in failed guidance system detection and isolation appears possible only if the engine thrust uncertainty is reduced to a relatively small value.

Although the present software and hardware limitations existing in the LM preclude the use of the RR in guidance monitoring, the equipment still plays a useful role during powered descent, particularly if an abort occurs. Normally, the LGC provides data for manual CSM search and lock-on or actually performs this task automatically. If the abort is necessitated by an LGC failure, the crew loses this capability and the command pilot must manually search to attain CSM lock-on. As this time period may be one of high crew task loading, it would appear operationally sound to leave the RR operating and locked-on during powered descent thereby relieving the crew of this time consuming procedure in an abort situation.

RECOMMENDATIONS

Based on the results of this study, it is recommended:

1. The RR be in a powered-up configuration and locked-on to the CSM during powered descent.

2. An analysis be made to determine the feasibility of having the LGC compute LM-CSM relative range and range rate during both powered descent and ascent.

REFERENCES

1. "A Preliminary Analysis of Failure Detection and Guidance System Monitoring During the LM Powered Descent," MSC Internal Note No. 66-EG-32, June 29, 1966.

2. "Usage of LM rendezvous radar during powered flight," memo from EG/Chief, Guidance and Control Division to FM/Technical Assistant for Apollo, EG43-488-66-997, September 20, 1966.